TOXIC SUBSTANCES IN LAKE ST. FRANCIS SEDIMENTS

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SLOTERDIJK, H.H. 1985. Toxic substances in Lake St. Francis sediments. Can. Tech. Rep. Fish. Aquat. Sci. 1368: pp. 249-264.

Lake St. Francis is formed by a widening of the St. Lawrence River after entering the Quebec Province at Cornwall, and is potentially one of the most contaminated waterbodies in Quebec. In order to determine whether the lake acts as a sink for toxic substances coming from Lake Ontario and the international section of the St. Lawrence River, a bottom sediment survey was carried out during 1979-1981 at about a hundred stations. The first 2-3 cm were analysed for particle size, mercury and PCB's. About 30 stations were also analysed for PAH's, while 10 were analysed for mirex, chlorobenzenes, pentachlorophenol and PBB's.

Only PAH's, PCB's and Hg were found at significant concentrations, up to 1800, 1900 and 1500 ng/g, respectively. Distribution patterns indicate that Lake Ontario has less of an impact on the Quebec part of the St. Lawrence River than was previously suspected. Local sources such as Cornwall (Hg) and the New York tributaries of the international section of the St. Lawrence (PCB's, PAH's) are most likely responsible for the high contaminant levels in the lake. Nevertheless, Lake Ontario remains a significant source of contaminants (PCB's, mirex) for the Quebec region.

Particle size distribution suggests that Lake St. Francis is governed more by fluvial than lacustrine conditions, sand being the predominant fraction. The lake does not form a contaminant sink, and an important fraction of toxic substances will move through the system out towards the Montreal area.

There is an urgent need for the development and application of bioassays sensitive enough to evaluate the significance and ecotoxicological aspects of contaminant levels in sediments.

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Le lac Saint-François, formé par un élargissement du fleuve Saint-Laurent après son entrée au Québec à Cornwall, est potentiellement un des plans d'eau les plus contaminés au Québec. Environ cent échantillons de sédiments de fond y ont été prélevés entre 1979 et 1981 afin d'évaluer le rôle du lac comme zone d'accumulation de substances toxiques provenant du lac Ontario et du tronçon international du fleuve Saint-Laurent. La couche supérieure (2-3 cm) des sédiments a été analysée pour la granulométrie, le mercure et les

PCB. Environ trente stations ont aussi été analysées pour les PAH, tandis que dix ont été analysées pour les chlorobenzènes et les PBB.

Seuls, les PAH, les PCB et le mercure ont été détectés à des concentrations significatives, soit jusqu'à 1800, 1900 et 1500 ng/g respectivement. Le patron de distribution spatiale indique que l'impact du lac Ontario sur la partie québécoise du fleuve Saint-Laurent est moindre que ce que l'on soupçonnait auparavant. Ce sont plutôt des sources locales, telles que Cornwall (Hg) et les tributaires new-yorkais du tronçon international du fleuve Saint-Laurent (PCB, PAH), qui sont responsables des niveaux élevés de contaminants dans le lac. Néanmoins, le lac Ontario demeure une source significative de substances toxiques (PCB, mirex) pour la région du Québec.

La granulométrie suggère que le lac Saint-François est plutôt caractérisé par des conditions fluviales que lacustres, le sable étant la fraction prédominante. Le lac ne forme pas une aire d'accumulation de contaminants et une importante fraction des substances toxiques sera acheminée en dehors du système vers la région de Montréal.

Il y a un besoin urgent pour le développement et l'application des tests biologiques assez sensibles pour évaluer la signification et les aspects écotoxicologiques des niveaux de contaminants dans les sédiments.

INTRODUCTION

Lake St. Francis is formed by a widening of the St. Lawrence River after entering the Province of Quebec at Cornwall (Figure 1). It receives the waters of the Great Lakes by way of the international section leaving Lake Ontario (Kingston - Cornwall), and drains therefore one of the most industrialized and urbanized areas of North America. Lake St. Francis can be considered as potentially one of the most contaminated waterbodies in Quebec. This has been confirmed by several studies (CESL, 1978). For example, Slcterdijk (1977) has found high concentrations of Hg and PCB's in fish, while Sérodes (1978) reported high levels of mercury in sediments.

In order to determine whether Lake St. Francis acts as a sink for toxic chemicals coming from the Great Lakes, and especially Lake Ontario, a sediment survey was carried out in 1979, 1980 and 1981. Some of the results of this survey (Hg, PCB's and PAH especially) will be discussed in this report.

Materials and Methods

About a hundred stations, located throughout the lake following roughly a grid system, were sampled during 1979, 1980 and 1981. Offshore stations were located using tellurometers (MRB 201) as described by Durette and Zrymiak (1978). Nearshore stations could be located using visual methods and compass readings.

Sediments were sampled using an Ekman dredge (15 x 15 cm) for the nearshore stations, and a Shipek (6600 cm^3) for the offshore stations.

The first 2-3 cm were taken and subsequently analysed for particle size, mercury and PCB's (Polychlorinated Biphenyls). About 30 stations were also analysed for PAH's (PolyAromatic Hydrocarbons) while 10 were analysed for mirex, chlorobenzenes, pentachlorophenol and PBB's (PolyBrominated Biphenyls).

Samples were preserved by freezing, and chemical analyses were carried out on the wet samples. Water contents was also determined and concentrations are reported on a dry weight basis. Particle size was determined by sieve, short pipette and settling tube analysis (Guy, 1969; Duncan and LaHaie, 1979). The fractions obtained represent: gravel, 2 mm; sand, 2 - 0.060 mm; silt, 0.060 - 0.004 mm; clay, 0.004 mm.

Mercury was determined by flameless atomic absorption spectrophotometry, after acid digestion and a permanganate/persulfate oxidation of the sediments. Reducing the mercury to its elementary form by stannous chloride permits air volatilization and subsequent measurement in an AA cell (Environment Canada, 1979).

Organic contaminants were determined using sediment extracts. PCB's, mirex, chlorobenzenes, pentachlorophenol and PBB's were analysed by gas-liquid chromatography (Environment Canada, 1979), while PAH's were analysed by High Pressure Liquid Chromatography (HPLC) according to a method described by Dunn and Armour (1980).

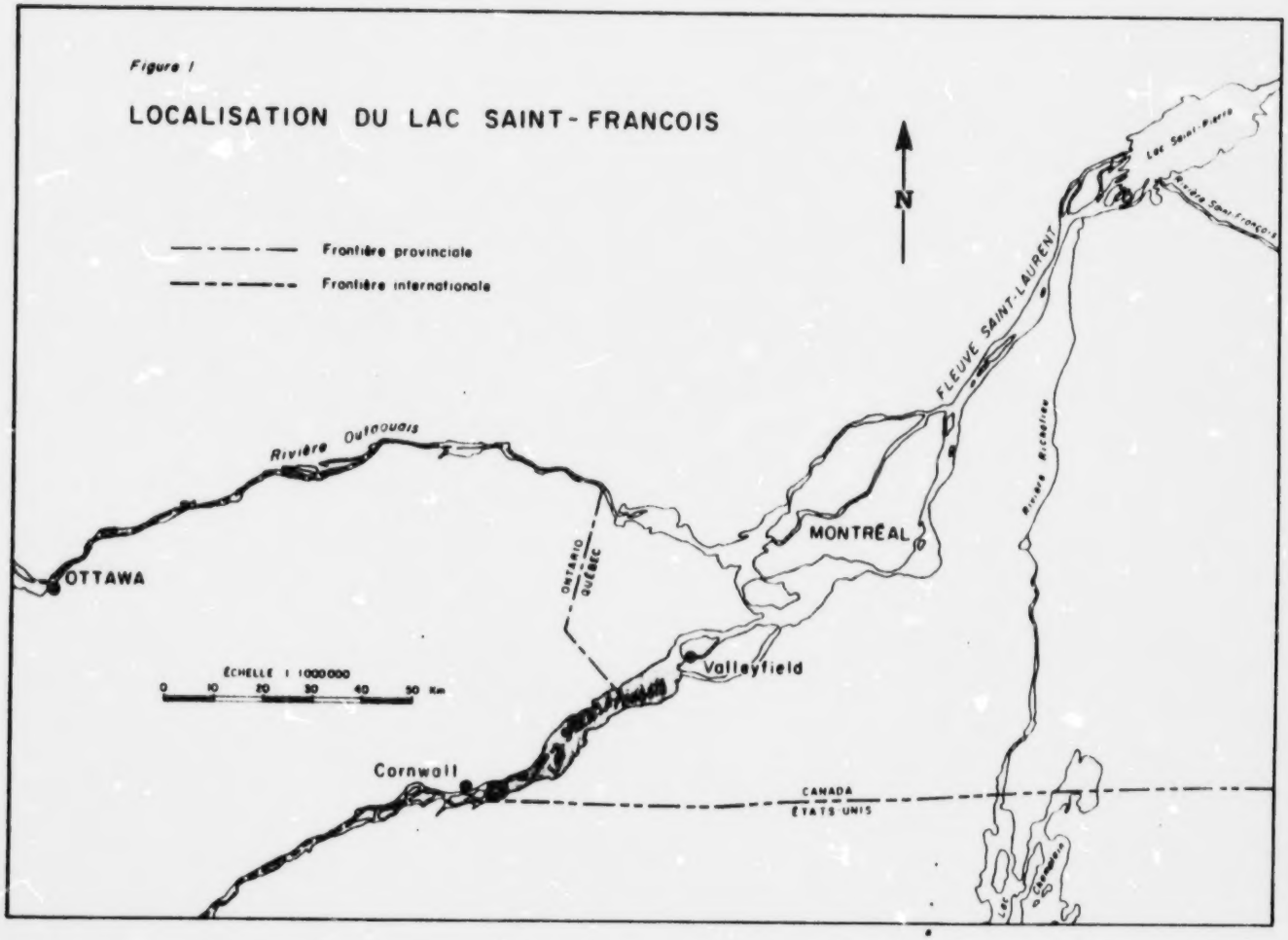

FIGURE 1 LOCALISATION DU LAC SAINT-FRANCOIS

RESULTS AND DISCUSSIONS

Study Area

To understand the lake and its hydrodynamics, some of its physical aspects should be mentioned. The lake forms a reservoir of about 230 km^2, with a length of about 60 km, and a width attaining a maximum of about 8 km. Hydro-electric dams upstream and downstream regulate its water level, which varies less than 0.5 m over a year.

There is no thermal stratification, the lake being fairly shallow. A significant current system ensures a short residence time of the water. The lake is also partially canalized for the St. Lawrence Seaway.

There are two major urbanized communities, one at each pole of the lake, Cornwall and Valleyfield. The Cornwall area is particularly industrialized and forms a potential source of contaminants, since it is located at the upstream end of the lake. As was mentioned before, Lake Ontario and the international section of the St. Lawrence River are important potential sources of toxic chemicals. The perimeter of the lake consists of a few villages and agricultural fields while the lake's tributaries drain an essentially agricultural region.

After the lake, the St. Lawrence River carries on by way of the Beauharnois canal towards Lake St. Louis and the Montreal area.

Particle Size

Results for particle size distribution are shown in Figure 2. This parameter is important, since it influences contaminant absorption. In general, smaller particles (e.g. clay) adsorb toxic chemicals to a greater extent than larger particles (e.g. sand), for reasons of chemical affinity and volume/surface area ratio. Organic carbon content also plays a role, and it is thought that PCB's, for example, are concentrated by organic matter in the sediments.

Throughout the lake we found mainly sand. The reason for this predominance of sand is thought to be due to the fluvial character of the lake. Being a widening of the St. Lawrence River, typical lacustrine conditions, i.e. no significant flow, are generally not observed. Furthermore, as the lake is fairly shallow and unstratified, wave action and turbulence caused by storms are significant as sorting mechanisms. This prevents the accumulation of fine materials, except in the eastern part of the lake. Here, a slowdown of the current and increased depth allow finer particles to settle out, and this area could be a potential deposition zone of contaminants.

Summarized Results (Table 1)

Results for parameters, which are of toxicological interest but found either at very low concentrations or below detection limits, will not be discussed in detail. PBB's and pentachlorophenol were not detected in the 10 samples that were analysed. Chlorobenzenes were either below, or at the most very close to detection limits. Only 3 of the 10 samples gave positive results. Hexachlorobenzene (HCB) was much more common and concentrations ranged up to 13 ng/g.

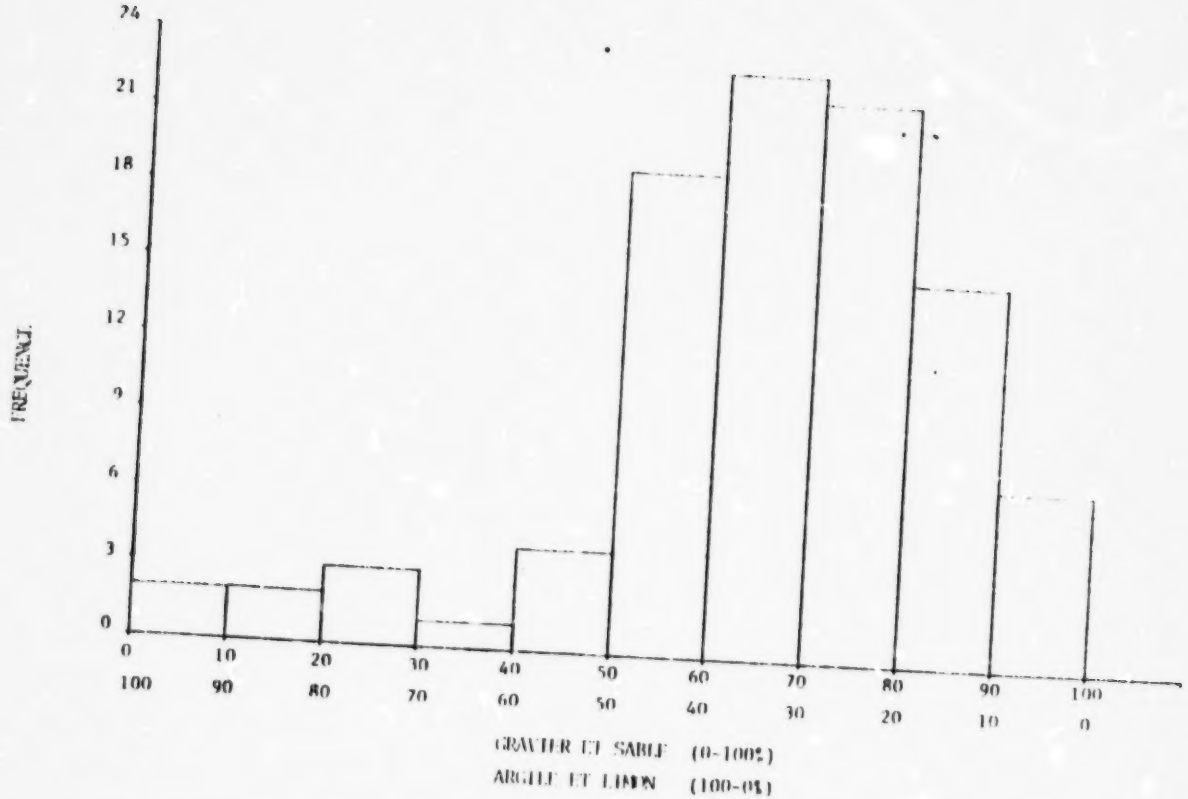

FIGURE 2 HISTOGRAMME DE FRÉQUENCE DES FRACTIONS D'ARGILE-LIMON (%) ET DE GRAVIER SABLE (%) DES SÉDIMENTS DU LAC SAINT-FRANÇOIS PRÉLEVÉS AUX 98 STATIONS D'ÉCHANTILLONNAGE (1979-81)

TABLE 1 SUMMARY OF ANALYTICAL RESULTS (ng/g)

Parameter	Median	Range
Hg	134	0.5 - 1474
PCB	170	1 - 1900
PAH total	552	31 - 1883
Benz(a)anthracene	53	4 - 120
Benz(b)fluoranthene	130	7 - 770
Anthracene & Phenanthrene	32	2 - 960
Fluoranthene	120	11 - 360
Benzo(k)fluoranthene	46	3 - 130
Benzo(ghi)perylene	70	2 - 190
Indeno(1, 2, 3-cd)pyrene	68	2 - 900
DDT(total)	1.5	<0.1 - 16.7
Mirex	< 1	<1.0 - 3.3
Chlorobenzenes:		
di-isomers	< 10	-
tri-isomers	< 1	<1 - 3
tetra-isomers	< 1	-
penta-isomer	< 1	<1 - 2
hexa-isomer	0.6	<0.1 - 13
Pentachlorophenol	< 2	-
PBB	< 10	-

Mirex was found at concentrations up to 3.3 ng/g. This is significant in environmental terms and indicates long range aquatic transport of pollutants, as the only known source of mirex is Lake Ontario. These results then confirm that pollutants originating in Lake Ontario are being transported down the St. Lawrence River into the Quebec Region.

In Table 1, results are also given for the parameters which were found at significant concentrations. These will be treated in more detail, although PAH's will be considered as total only. Three carcinogens are included in the list of PAH's analysed, benz(a)anthracene, benzo(b)fluoranthene and indeno(1, 2, 3-cd)pyrene, which were found at concentrations up to 120, 770 and 900 ng/g, respectively. Unfortunately, the significance of these concentrations in ecotoxicological terms is not known.

Mercury

Results for mercury are summarized in a frequency histogram (Figure 3). Generally, concentrations up to 100 ng/g can be considered as natural (Sloterdijk et Azzaria, 1981). From the frequency histogram it can be seen that about 40% are below this level. The Ontario Ministry of Environment guideline for open water disposal of dredged sediments is 0.3 mg/kg, or 300 ng/g (Levings, 1982). According to this guideline, about 70% of the stations sampled do not present any significant problems. However, it means that 30% of the stations are contaminated, some of which present quite high concentrations, between 1000 - 1500 ng/g.

As can be seen in Figure 4, mercury concentrations are not distributed throughout the lake in a random fashion. A definite pattern is quite evident, the northern part of the lake being much more contaminated than the southern section. It can also be seen that the most contaminated sediments are found in the Cornwall area.

This spatial pattern cannot be explained by differences in particle size. We have to look at possible point sources. At Cornwall, sediments are highly contaminated with mercury, mainly by effluents of a chlor-alkali plant. Up until the beginning of the seventies, this plant was using a mercury electrode. Although mercury is not being used anymore, the contaminated sediments remained, and these are being carried downstream by the prevailing currents. Wave action and turbulence during storms will cause a resuspension of the sediments, to be dropped further downstream. With time, there is a steady migration of mercury along the north shore of the lake. The south shore does not seem to receive any significant amounts of mercury, nor is there cross-sectional transport from the north shore to the south shore, as is to be expected from the current pattern.

Polychlorinated Biphenyls (PCB's)

Polychlorinated biphenyls, a mixture of isomers of various chlorine contents, are synthetic compounds and therefore do not occur naturally in the environment. Yet, because of their versatility and specific properties, industrial applications of these compounds have been widespread, with the resulting contamination of the environment (Task Force, 1976). Today, uses of PCB's are almost completely prohibited (Anon., 1982), although it is expected that sources will continue to exist, and that the PCB problem will remain with us for a while to come.

Results are summarized as a frequency histogram in Figure 5. The Ontario Ministry of the Environment guideline for open water disposal of dredged sediments is 50 ng/g (Levings, 1982). From the histogram it is evident that most stations, about 80%, are

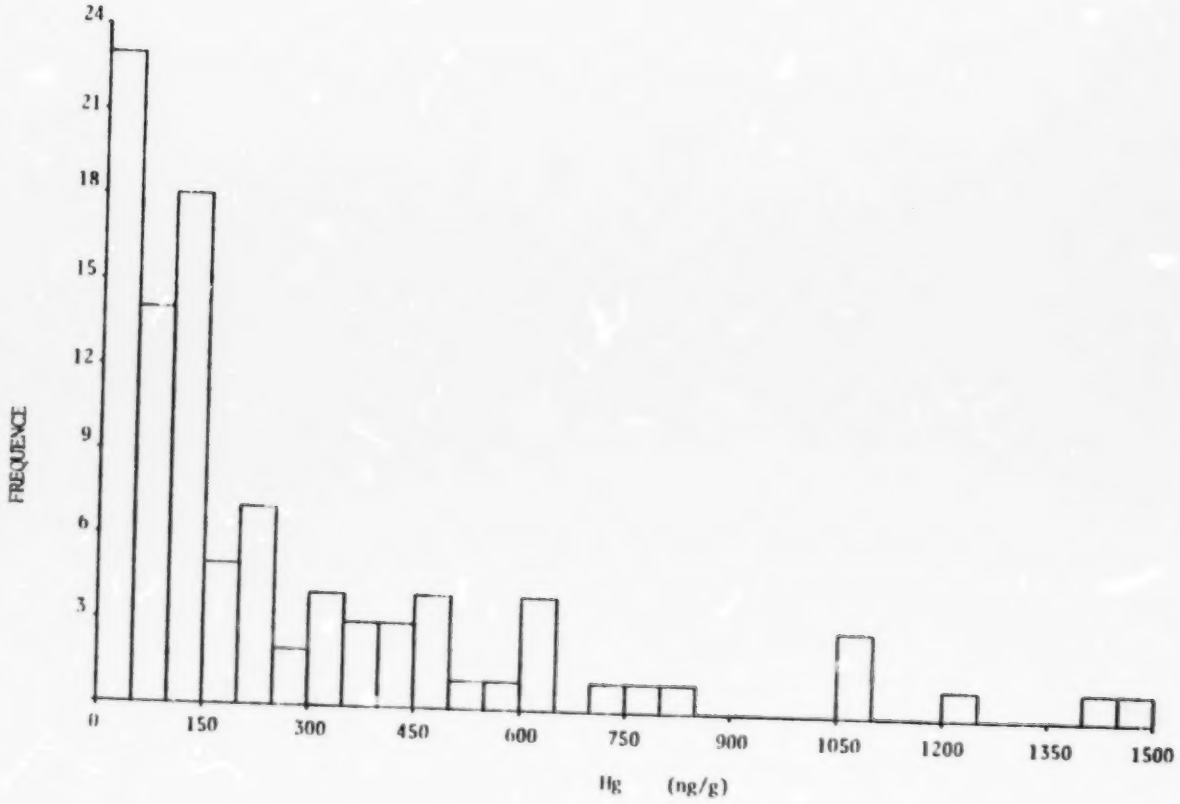

FIGURE 3 HISTOGRAMME DE FRÉQUENCE DES CONCENTRATIONS EN HG (ng/g) DES SÉDIMENTS DU LAC SAINT-FRANÇOIS PRÉLEVÉS AUX 98 STATIONS D'ÉCHANTILLONNAGE (1979-81)

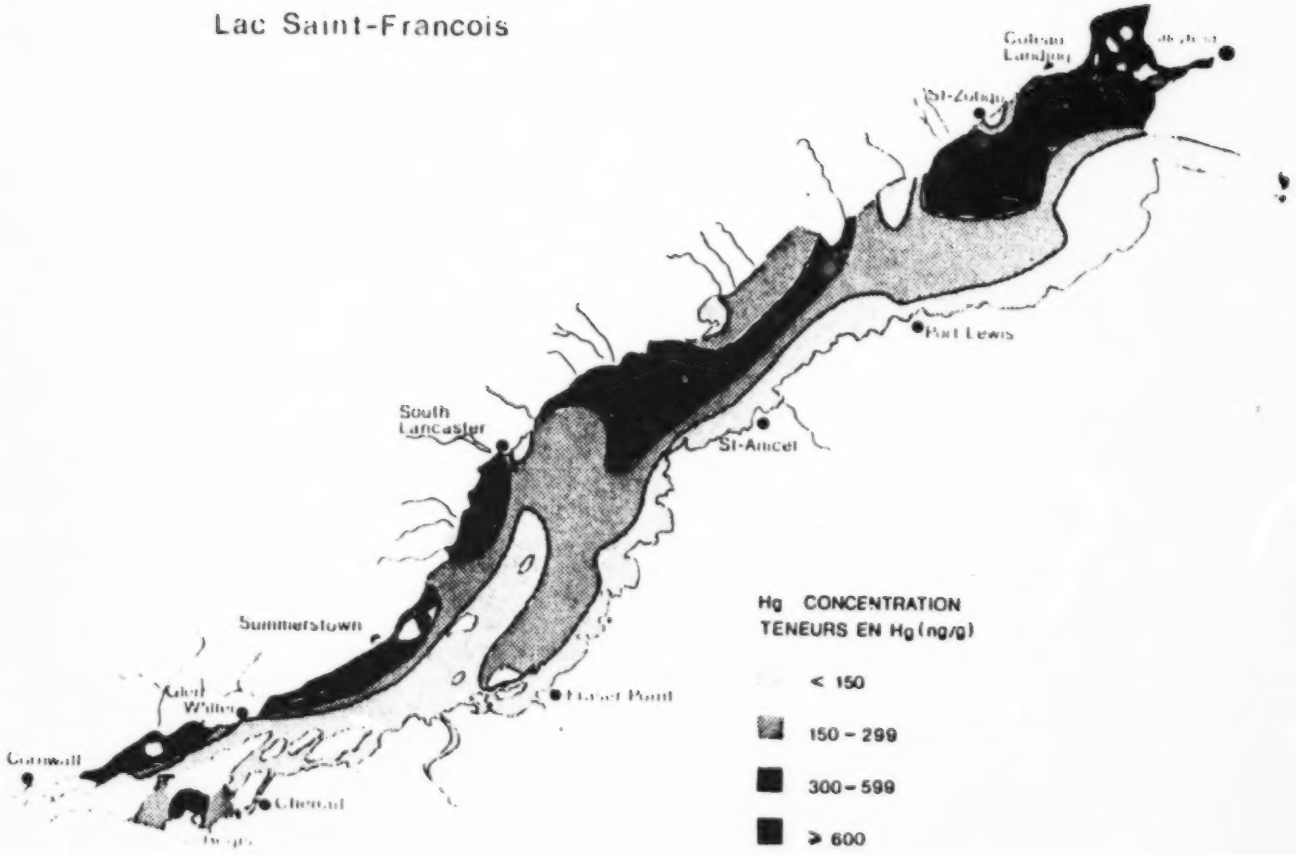

FIGURE 4 SPATIAL DISTRIBUTION OF HG CONCENTRATION IN LAKE ST. FRANCIS SEDIMENTS

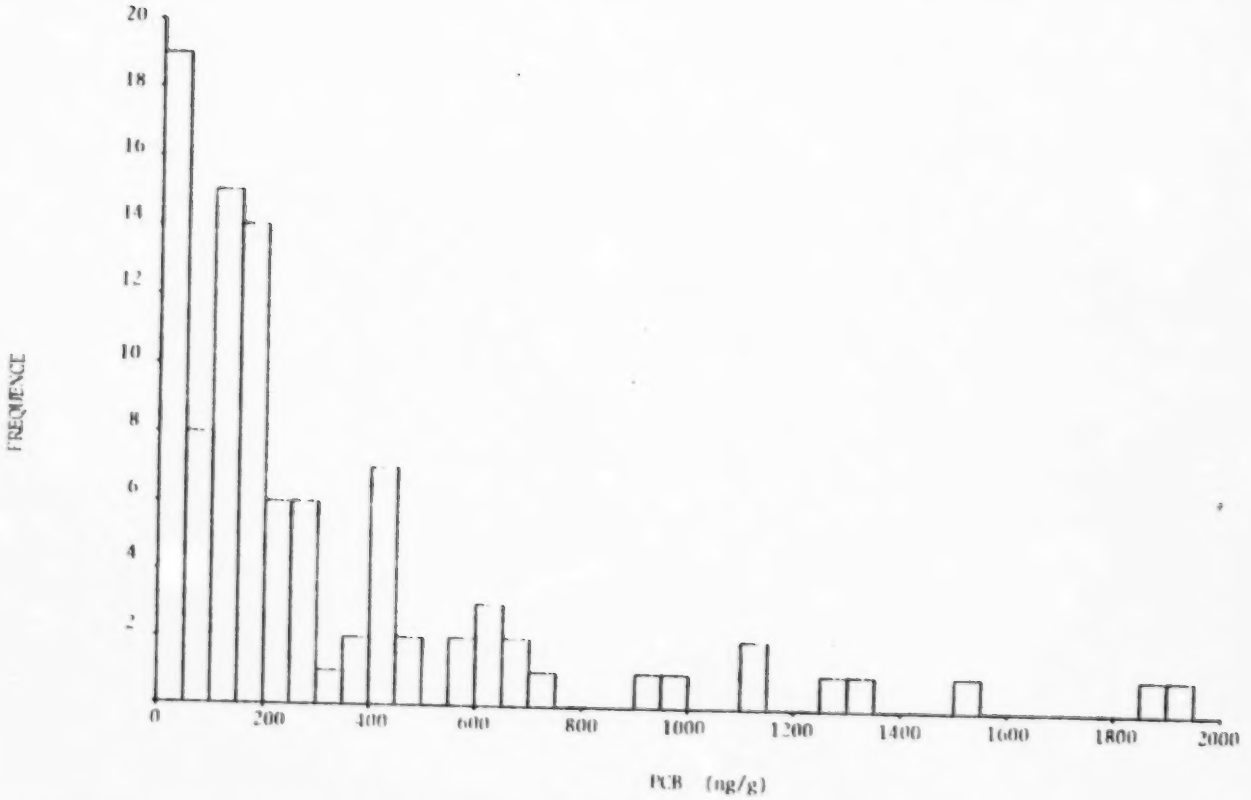

FIGURE 5 HISTOGRAMME DE FRÉQUENCE DES CONCENTRATIONS EN PCB (ng/g) DES SÉDIMENTS DU LAC SAINT-FRANCOIS PRÉLEVÉS AUX 98 STATIONS D'ÉCHANTILLONNAGE (1979-81)

above this guideline. It can be inferred that they may present problems to the aquatic ecosystem. About 50% of the stations are below 200 ng/g, while about 10% are over 800 ng/g, up to 2000 ng/g.

Spatial distribution is presented in Figure 6. It shows a distinct pattern as well but, in contrast to mercury, we found higher concentrations along the south shore. The highest concentrations are found at the entrance of the lake, along the south shore, and at a few places which seem to be particular deposition zones. This is very evident at the east-end of the lake, already identified as a deposition area based on depth and current velocity.

Particle size or organic carbon contents cannot explain this pattern. There seems to be a source upstream from the lake. It is believed that the New York tributaries of the international section of the St. Lawrence River contribute significant amounts of PCB's to the system. It has been reported that at least one tributary, the Grasse River, is highly contamined with PCB's (Chan, 1980). Thus we have here an example of transboundary pollution, which is brought to light by a sediment survey.

Polyaromatic Hydrocarbons (PAH's)

Seven different types of PAH'S were analysed (Table 1), of which three are known carcinogens, benz(a)anthracene, benzo(b)fluoranthene and indeno(1, 2, 3-cd)pyrene.

To simplify this presentation, only total PAH's will be discussed. Concentrations for the individual compounds have been presented previously in Table 1.

The spatial distribution pattern is shown in Figure 7. It is apparent that there is a similar pattern as that observed for PCB's: the south shore is generally more contaminated than the north shore. Concentrations are high near the entrance of the lake, especially in the southern section, therefore it seems that New York tributaries are most likely significant sources of PAH's. There is, however, a pocket of high concentrations near the north shore, just downstream from Cornwall. The most likely explanation seems to be the presence of a sewage treatment plant, which has an outlet pipe (diffuser type) just upstream from Pilon Island.

CONCLUSIONS AND RECOMMENDATIONS

The distribution pattern for PCB's and PAH's indicate high concentrations along the south shore, while mercury concentrations were high along the north shore. It is concluded from this that Lake Ontario may have less an impact on the Quebec part of the St. Lawrence River than was previously suspected. Local sources such as Cornwall and the New York tributaries of the international section of the St. Lawrence are probably responsible for the observed distribution patterns.

However, the fact that mirex was found in significant quantities and that PCB concentrations are high throughout the whole lake, indicates that Lake Ontario remains a significant source of organic contaminants.

Particle size distribution suggests that Lake St. Francis is governed more by fluvial than lacustrine conditions, sand being the predominant fraction at most stations. This then indicates that the lake does not act so much as a contaminant sink, but that most

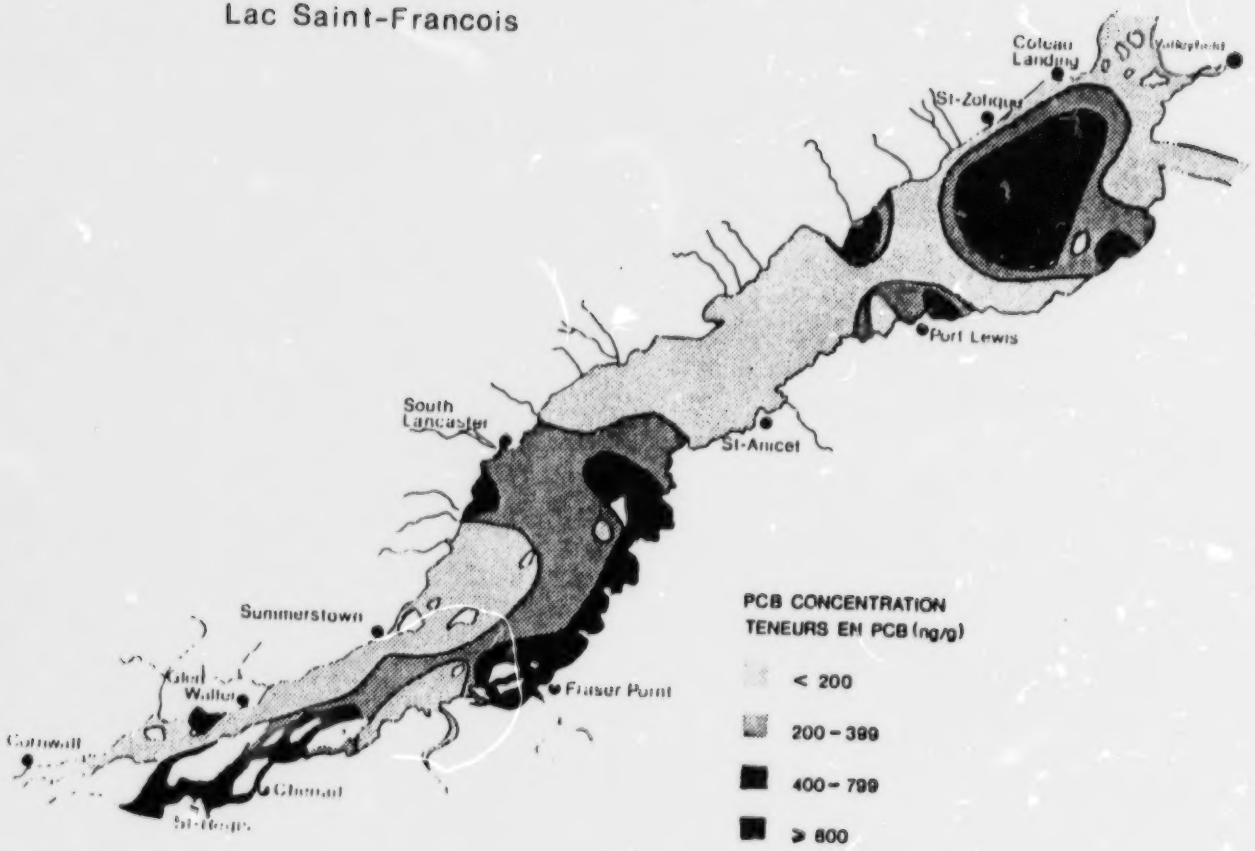

FIGURE 6 SPATIAL DISTRIBUTION OF PCB CONCENTRATION IN LAKE ST. FRANCIS SEDIMENTS

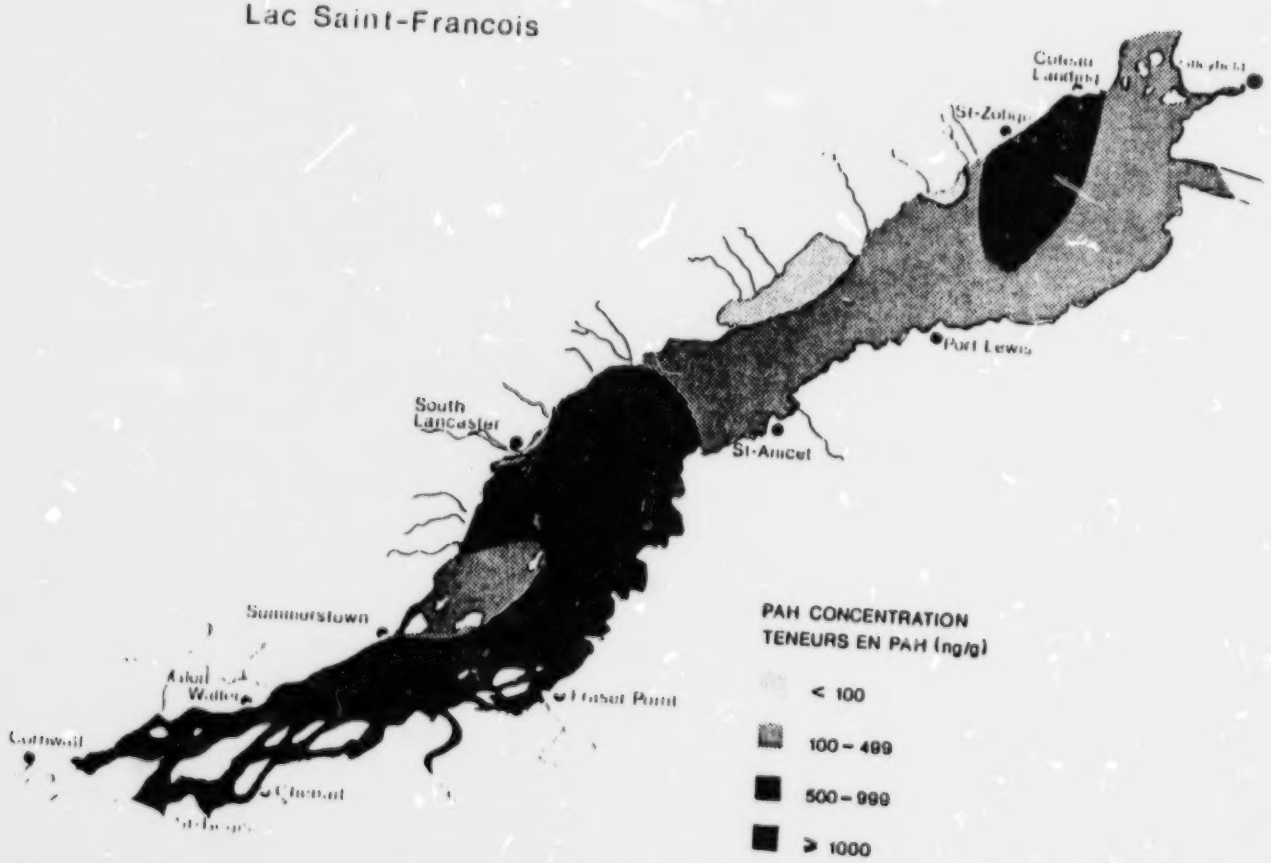

FIGURE 7 SPATIAL DISTRIBUTION OF PAH CONCENTRATION IN LAKE ST. FRANCIS SEDIMENTS

toxic substances entering the lake from upstream move through the system and out towards the Montreal area.

In closing, it seems appropriate to say a few words on biomonitoring of toxic substances in the environment. This paper has dealt with what might be called "Ambient Level Monitoring", which tells us how much of a given substance is present in a particular environment. However, it does not qualify this information nor determine whether there is a significant impact on the ecosystem.

Therefore, there is an urgent need to develop the tools and methods to study toxic effects or stress factors in the natural environment. As is apparent from some of the papers given at this workshop, bioassays are now carried out using very sensitive and refined techniques, but they are mainly limited to particular toxic chemicals or industrial effluents. These studies are important, and they do provide much information, but it is still very difficult to predict the effects of toxic chemicals that are being found in a particular ecosystem. Ecotoxicology is a popular concept today, yet if we do not address real ecosystems in the field, and not only in the laboratory, then the term ecotoxicology loses its true meaning.

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